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Instantaneous Power Theory Based Unified Power Quality Conditioner (UPQC)

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Abstract: This paper presents a novel control strategy for a 3-phase 3-wire Unified Power-Quality Conditioner (UPQC) based on the concepts of instantaneous active and reactive Power theory. The UPQCs is one of the major custom power solutions capable of mitigating the effect of supply voltage sags / swells, distortion, unbalance voltage at the point of common coupling (PCC) as well as load harmonics, unbalance load and reactive power requirement of load. Using this control strategy harmonic detection, reactive power compensation, voltage sag and swell have been simulated and the results are analyzed. The operation and capability of the proposed system was analyzed through simulations with MATLAB / SIMULINK

Keywords: Active filters, instantaneous power theory, power quality, Unified Power Quality Conditioner (UPQC**)**

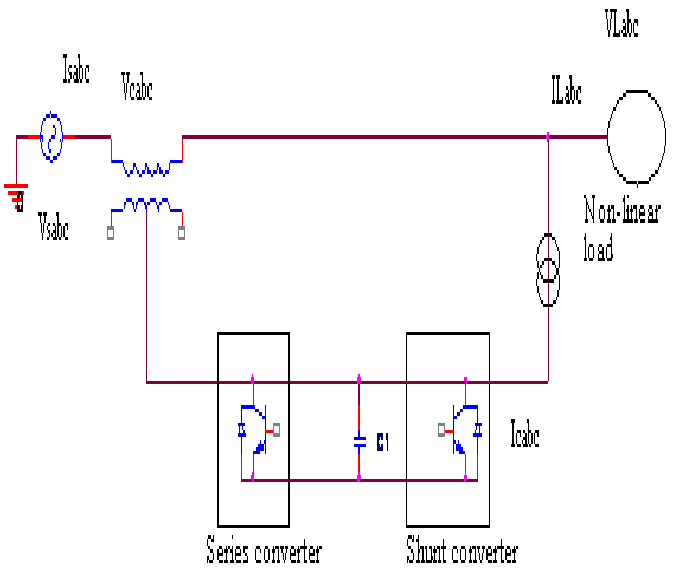
I INTRODUCTION

Today, Industry automation utilizes power electronic based power processing devices (variable voltage, variable frequency and current control) for getting higher efficiency, accurate controllability, faster response and compact size. But on the other side, due to the switching actions, these power electronics devices (SCR, MOSFET, BJT and IGBT) behave as non-linear loads and they draw non-sinusoidal and/or lagging/leading current from the supply resulting to poor displacement and distortion factors. Hence these power converters draw considerable reactive volt-amperes from the utility and inject harmonics in distribution networks. The harmonic current from these power converters flows through the line and due to the presence of source impedance of the power system it can cause voltage distortion (harmonic voltage) and excessive voltage drop and line losses [1], [2]. The distorted supply voltage results in malfunction of control, protection, and metering equipment used in other sensitive loads and industrial automation monitoring devices. Harmonic currents can also cause, unwanted system resonance with passive filters, overloading of power factor correcting capacitors, decrease in overall system efficiency due to increased line and machine losses, interference with communication and control signals, and saturation and overheating of distribution transformers and lines [2]. At the same time, an increase of sensitive loads involving digital electronics and complex process controllers requires a pure sinusoidal supply voltage for proper control and load operation.

This forces the industries to filter the harmonics and compensate the reactive power. The immediate and cheap solution is passive filters. But it has its own limitations such as harmonic resonance and harmonic amplification due to varying line impedance. In addition to this, the effectiveness of the passive filters is purely based on line and source impedance and load parameters, which is highly unpredictable.

The advancement in power electronic devices combined with the active filter technology has resulted in providing a suitable source for compensation for harmonics, reactive power, unbalance and/or neutral current in ac networks [2]. Active filters can be classified based on converter type, topology, and the number of phases. The converter type can be either Current Source Inverter (CSI) or Voltage Source Inverter (VSI) bridge structure. The topology is the way in which the CSI/VSI is connected to load or source, and can be connected in shunt [9], series, or a combination of both [1].

The third classification is based on the number of phases, such as two-wire (single phase) and three- or four-wire three-phase systems. Active filtering and the application of FACTS concepts in electric power transmission system then in to distribution systems has resulted in all the functionalities in a single compensating device called as UPQC[2]



The series and shunt converters connected back-to-back via a common DC link capacitor. Unlike the UPFC, here the series converter is connected to the supply side and shunt converter is connected the load side. This configuration has proved its capability to reduce both supply voltage distortions such as sag, swell, harmonics and unbalanced line to line voltages as well as load disturbances such as harmonic current, unbalanced load and reactive power requirement by the load [4],[6]. This configuration also provides optimum rating for a specific amount of sag / swell and reactive power compensation. The schematic of the scheme is shown in Fig.1. The UPQC controller was designed using the instantaneous power method based on α-β-0 transform and fundamental positive sequence detection [3]. This configuration and control strategy is suitable for all the power quality issues discussed above with very good transient and steady state operation.

II CONFIGURATION OF UPQC

The UPQC is aimed for simultaneous compensation of the load current distortion and the supply voltage disturbance. UPQC has two voltage-source inverters of three-phase three-wire configuration connected back to back through same DC link capacitor [2]. Source side inverter, called the series inverter is connected through coupling transformers between the point of common connection and load. The load side inverter, called the shunt inverter is connected in parallel to the bus either directly or through a transformer. The series inverter operates as a controlled voltage source, while the shunt inverter operates as a controlled current source [4]. So, the UPQC has compensation capabilities for the load harmonic current, the reactive power compensation, the source voltage disturbances (including sag / swell), and the unbalance (load and source) compensation [1].

III UPQC CONTROL STRATEGY

The control system has three major elements, such as positive sequence detector, shunt inverter control, and series inverter control [3], [5]. The positive-sequence detector extracts the positive sequence component from the disturbed and unbalanced three-phase source voltage using the steps elaborated in Fig. 2 having a sub block. The transformed positive sequence reference voltage $V_{s\alpha}'$, $V_{s\beta}'$, based on the α-β-0 transform are found out as explained below. The measured source voltage passes through the three phase PLL (Phase-Locked Loop) and the sine wave generator to calculate the fundamental component of the α-β transformed current, ($i\alpha'=\sin\omega 1t$) and ($i\beta'=\cos\omega 1t$) [5]. Similarly the V_{sabc} is divided by k(=(Vrms/sqrt(3))*sqrt(2)) for getting the unit magnitude voltage signals. The powers corresponds to positive sequence fundamental component are calculated as active power p_s' and reactive power q_S' from the of the source voltage VS and fundamental current components i_α' and i_β' [3], [5].

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} X \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} p_s' \\ q_s' \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha' \\ i_\beta' \end{bmatrix} \quad (2)$$

So, the instantaneous value of the positive-sequence component voltage is calculated using the expression (3).

$$\begin{bmatrix} V_{s\alpha}' \\ V_{s\beta}' \end{bmatrix} = \frac{1}{i_\alpha'^2 + i_\beta'^2} \begin{bmatrix} i_\alpha' & i_\beta' \\ i_\beta' & -i_\alpha' \end{bmatrix} \begin{bmatrix} p_s' \\ q_s' \end{bmatrix} \quad (3)$$

A. Shunt Inverter Control

The functions of the shunt inverter are to compensate the current harmonics, the reactive power, and to regulate the DC link capacitor voltage. Fig.2 shows the configuration of shunt inverter control, describing the current control for harmonic compensation, and the DC bus voltage control. Shunt control calculates the reference value of the compensating current taking into account the harmonic component present in the load current, the load reactive power, the real power demand of series inverter to compensate sag / swell and the power loss *ploss* due to the inverter operation [10]. The information about the real power demand by the series compensator and the power loss in the converters can be obtained through DC link voltage regulator. The instantaneous power is calculated using α- cop positive sequence voltage and load current i_L βmonents ofas depicted in (4).

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_{s\alpha}' & v_{s\beta}' \\ v_{s\beta}' & -v_{s\alpha}' \end{bmatrix} \begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} \quad (4)$$

Where $\mathbf{i}_{L\alpha\beta}$ is the transformed component of load current $\mathbf{i}_{Labc}$. Moreover, the power corresponding to harmonic content is calculated, by separating oscillating power and fundamental power, by passing through a 5th order butter-worth high pass filter [3].Using these active powers (oscillating power and system power loss) and reactive power reference value of the compensating current is derived as in (5)

$$\begin{bmatrix} i^*_{c\alpha} \\ i^*_{c\beta} \end{bmatrix} = \frac{1}{U} \begin{bmatrix} V_{s\alpha}' & -V_{s\beta}' \\ V_{s\beta}' & V_{s\alpha}' \end{bmatrix} \begin{bmatrix} -p\sim + p_{loss} \\ -q \end{bmatrix} \quad (5)$$

Where $U = V_{s\alpha}'^2 + V_{s\beta}'^2$.

B. Series Inverter Control

The function of the series inverter is to compensate the voltage disturbance such as voltage harmonics, sag/ swell on the source side, which is due to the fault and/or line drop because of over load in the distribution line. The series inverter control calculates the reference voltage to be injected by the series inverter, comparing the positive-sequence component (Vabc') with the disturbed source voltage (Vsabc) [3]. The sag / swell compensation may involve supplying / absorbing real power from the supply line. The instantaneous real power absorbed / delivered by the series inverter must be equal to the real power delivered / absorbed by the shunt inverter so as to maintain DC link capacitor voltage constant [7], [8]. Fig. 3 shows the control circuit of series converter. In the Fig. 3, k=(Vrms/sqrt(3))*sqrt(2) and G=desired maximum phase voltage value.

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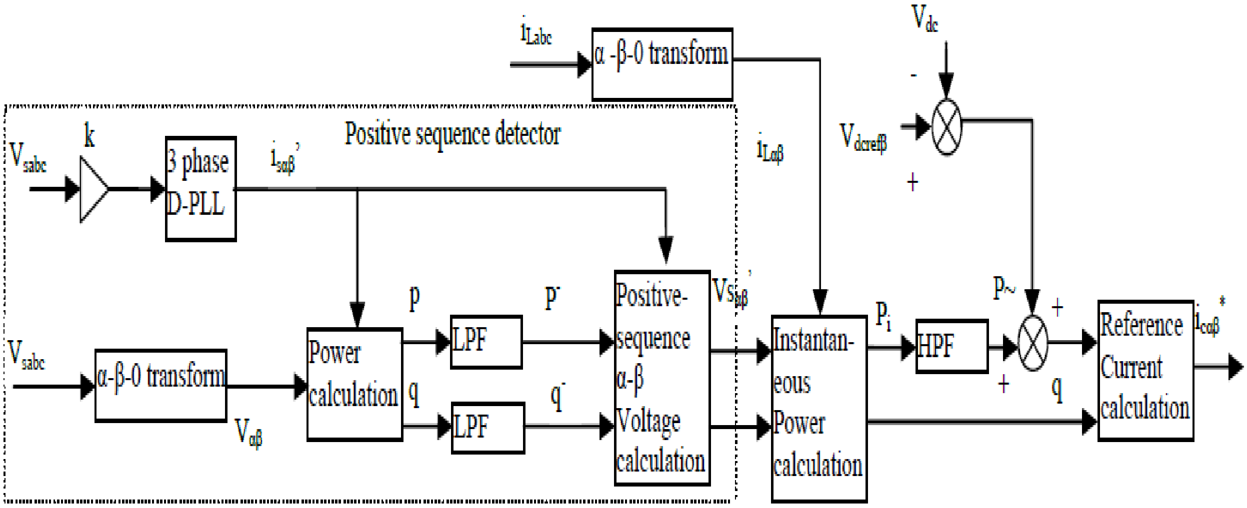

Figure 2 Shunt inverter control

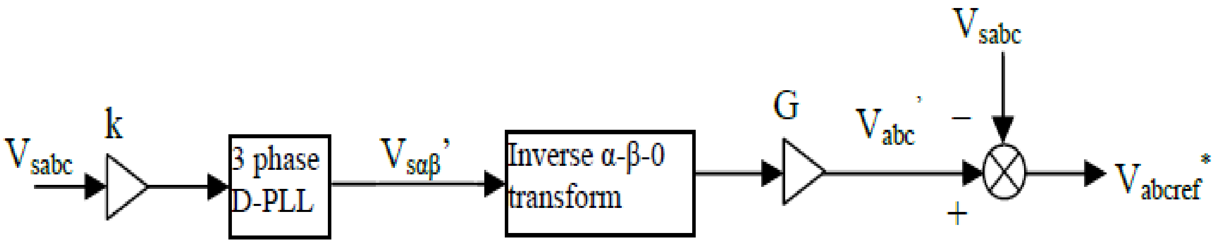

Figure 3. Control Circuit for Series converter

IV SIMULATION RESULT

Computer simulations with MATLAB/SIMULINK software were performed for the purpose of analyzing the operation of UPQC. The power circuit is modeled as a 3-phase 3-wire system with a non-linear load that is composed of a 3-phase diode-bridge rectifier with RL load.

The sag / swell can be realized with the programmable source at desired instant and desired magnitude. The circuit parameters used in the simulation is shown in Table I. The maximum simulation time was set up to be 300 ms. The shunt inverter started to operate at 40 ms, while the series inverter started to operate at 80 ms and the sag introduced in the system is from 120 ms to 200 ms. Fig. 4 shows the shunt inverter operation, the 1st, 2nd, 3rd and 4th graph shows respectively the current waveform of the load, source, shunt inverter reference current and the DC link voltage which confirms the active filter operation. Once the shunt converter started its operation the load harmonics and reactive power required by the load is compensated by injecting equal magnitude of harmonics in opposite polarity. The hysteresis current controller is used for synthesizing the compensating current with the current track band width of 0.02 ampere. The reference current of shunt inverter consists of harmonic components of nonlinear load, reactive current corresponding to load reactive power, power losses due to inverters and DC voltage regulation current.

Table I Simulation parameters

Source	Voltage Impedance	V=415, 50 Hz R=.01 Ω, L=.1 mH
DC Link	Reference Voltage Capacitor	600 V C1=5000µF, C2=5000 µF
Shunt Inverter	Filter	L=1.5 mH, C=10 µF
Series Inverter	Filter parameters Switching frequency	L=1.5 mH, C=10 µF 10 kHz
Load	Non linear load Linear Load	P=5 kW, Q=5kW P=2kW

The THD of the load current in graph 1 is 29.6% and is reduced to 3.7% with unity power factor operation in the source side with the help of shunt converter. Looking carefully to the graphs we can establish that the response time is less than quarter cycle (5 ms), which is more then sufficient for any real time application.

Fig. 5 shows the compensated result when the voltage sag occurs on the source side at 120 ms. All the three phases have 20% of sag voltage as shown in the 1st graph. The 2nd graph indicates the load voltage after compensation by the UPQC. The reference voltage for getting the desired compensation is generated by the series inverter with the help of PWM technique using a carrier wave of 10 kHz frequency. The real power injected by the series inverter during sag is compensated by shunt converter current on instantaneous basis. It is known that during the sag the current drawn from the source in increased a little. Fig. 6 shows the result corresponding to series compensation carried out for overcoming a voltage distortion. It is assumed that 3rd and 5th order harmonics of 0.2 pu are added from 120 ms to 200 ms as shown in the 1st graph. The 2nd graph indicates the output voltage across the load after compensation by the UPQC

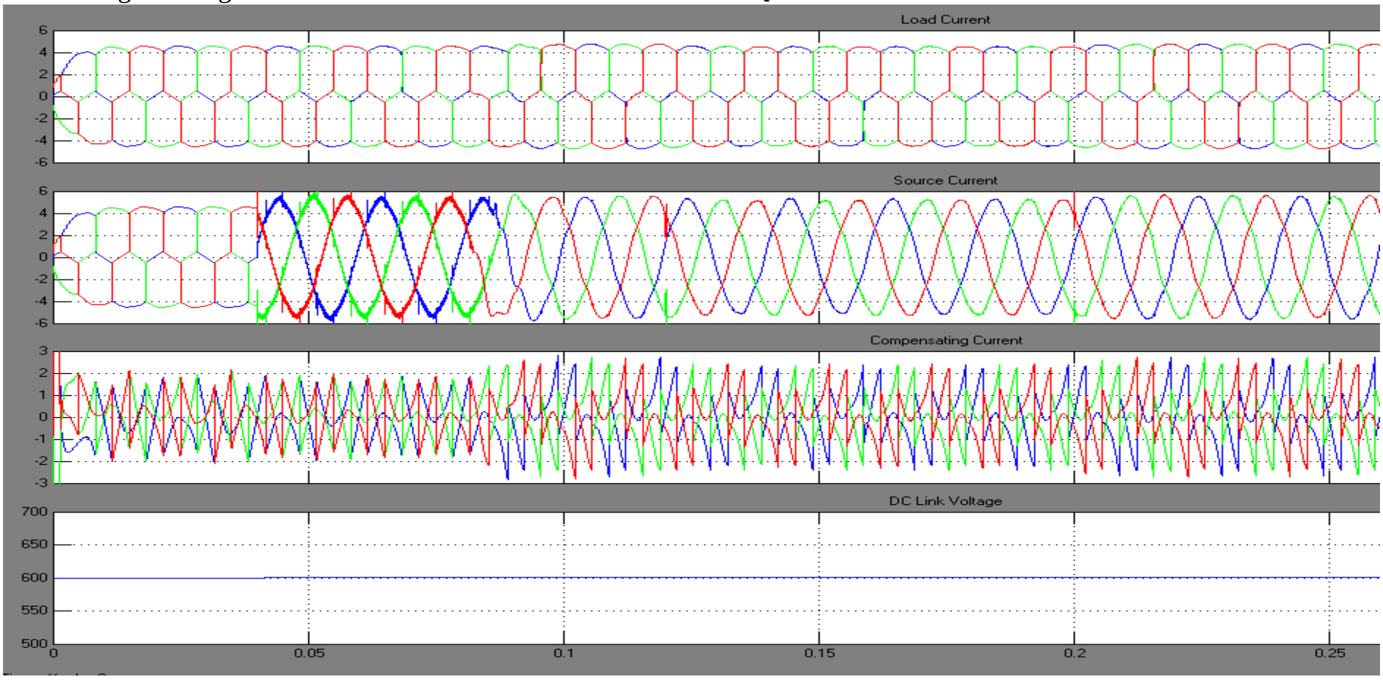

Figure 4 Shunt inverter operation under non-linear load

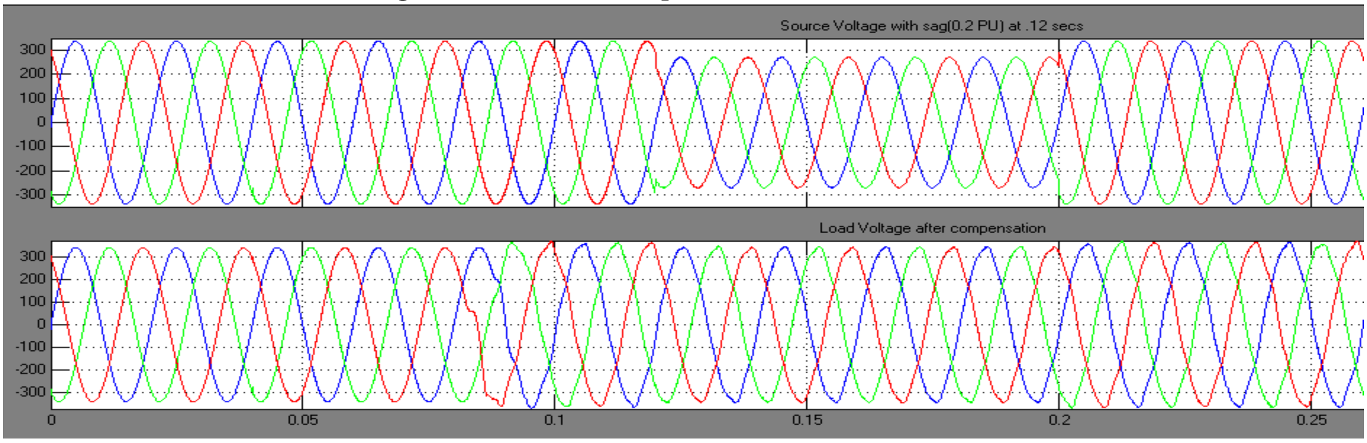

Figure 5. Source voltage with sag and compensated voltage

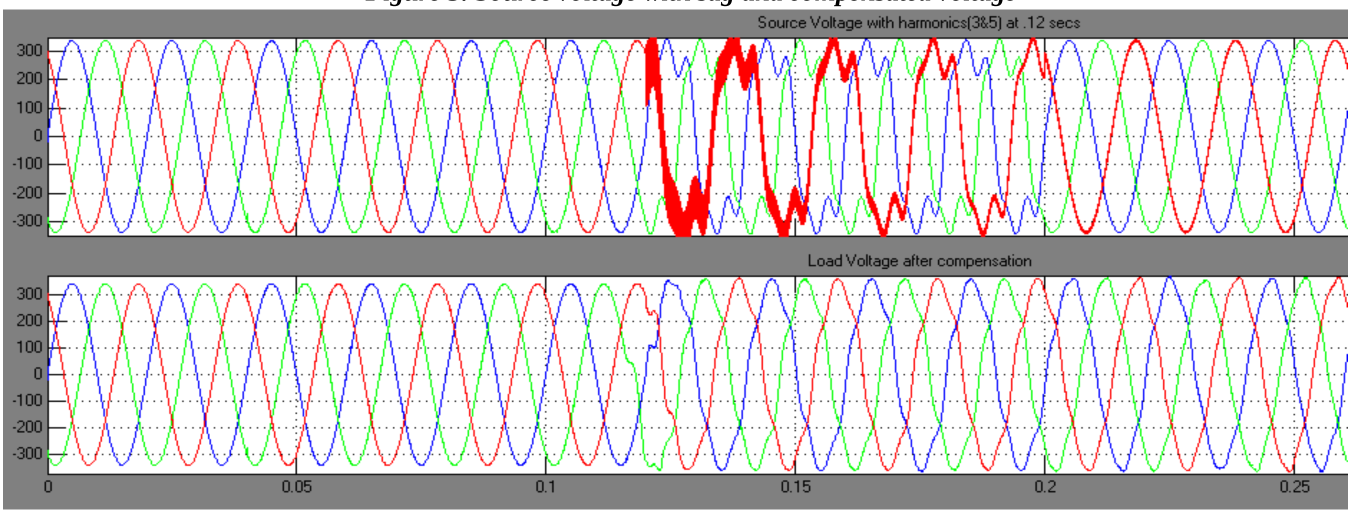

Figure 6. Source voltage with harmonics and compensated voltage

V CONCLUSION

A novel control strategy to generate the reference source current and reference load voltage under distorted and unbalanced load and source condition is presented in this paper. The UPQC can compensate the reactive power, harmonic current, voltage sag and swell, and voltage imbalance. The MATLAB/Simulink-based simulation results show that the distorted and unbalanced load currents seen from the utility side act as perfectly balanced source currents and are free from distortion.

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